Geosyntec consultants

Quantitative Passive Diffusive Sampling for Assessing Soil Vapor Intrusion to Indoor Air

Todd McAlary and Hester Groenevelt, Geosyntec Consultants, Inc.,
T. Gorecki and Suresh Seethapathy, University of Waterloo,
D. Crump, Cranfield University,
P. Sacco, Fondazione Salvatore Maugeri,
H. Hayes, Air Toxics Limited,
M. Tuday, Columbia Analytical Services,
B. Schumacher, USEPA,
P. Johnson, Arizona State University

28 March 2012

Geosyntec consultants

Overview

- Rationale
- Laboratory and Field testing for Indoor Air
- Laboratory and Field Testing for Soil Vapor
- Cost Comparisons

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
28 MAR 2012		**00-00-2012 to 00-00-2012**

4. TITLE AND SUBTITLE	5a. CONTRACT NUMBER
Quantitative Passive Diffusive Sampling for Assessing Soil Vapor Intrusion to Indoor Air	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Geosyntec Consultants, Inc,2002 Summit Blvd, NE Suite 885,Atlanta,GA,30319**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
Presented at the 9th Annual DoD Environmental Monitoring and Data Quality (EDMQ) Workshop Held 26-29 March 2012 in La Jolla, CA. U.S. Government or Federal Rights License

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**19**	

Geosyntec consultants

Passive Samplers

ATD Tubes

3M OVM 3500

The mass (M) and time (t) are measured accurately. Key is to know the uptake rate (k^{-1})

$$C_0 = \frac{M}{k^{-1}t}$$

Waterloo Membrane Sampler™

SKC Ultra II

Radiello™

Differences: size, uptake rates, sorbents, medium of uptake, method of analysis

3

Geosyntec consultants

Benefits of Passive Sampling

- Simple (minimal training, less risk of leaks)
- Time-weighted average concentration
  (up to a week or a month if needed)
- Low reporting limits with no premium cost
- Smaller – easy to ship, discrete to deploy
- Long history of use in Industrial Hygiene
- Less expensive
- Other benefits unique to each sampler

4

Geosyntec consultants

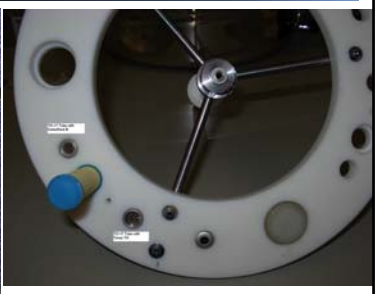
Laboratory Test Compound List

Analyte	Koc (mL/g)	OSWER indoor conc. at 10^{-6} risk (ppb)	Vapour pressure (atm)	Water solubility (g/l)
1,1,1-Trichloroethane	**110**	400	0.16	1.33
1,2,4-Trimethylbenzene	**472**	1.2	0.00197	0.0708
1,2-Dichloroethane	**174**	0.023	0.107	8.52
2-Butanone (MEK)	**134**	340	0.1026	~ 256
Benzene	**59**	0.10	0.125	1.75
Carbon tetrachloride	**174**	0.026	0.148	0.793
Naphthalene	**2,000**	0.57	0.000117	0.031
n-Hexane	**3,000**	57	0.197	0.0128
Tetrachloroethene	**155**	0.12	0.0242	0.2
Trichloroethene	**166**	0.22	0.0948	1.1

5

Geosyntec consultants

Experimental Apparatus



24 chambers x
5 sampler types x
3 replicates x
10 chemicals
= 3600 measurements

6

Geosyntec consultants

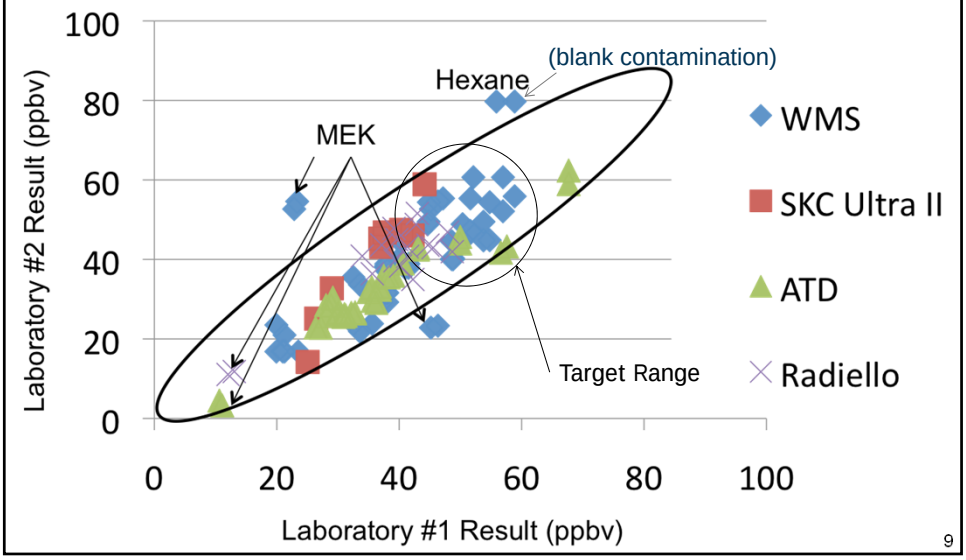
Inter-Laboratory Testing

Sampler Type	Home Laboratory	Secondary Laboratories	# of Samplers to Each Laboratory
Waterloo Membrane Sampler	University of Waterloo	Air Toxics Ltd Airzone One	2
ATD Tubes with Tenax TA	Air Toxics Ltd	Columbia Analytical Services University of Waterloo	2
ATD Tubes with CarboPack B	Air Toxics Ltd	Columbia Analytical Services University of Waterloo	2
SKC Ultra	Columbia Analytical Services	Air Toxics Ltd Airzone One	2
Radiello	Fondazione Salvatore Maugeri	Columbia Analytical Services Air Toxics Ltd	2

8

Geosyntec consultants

Interlab Test – Youden Plot



9

Geosyntec consultants

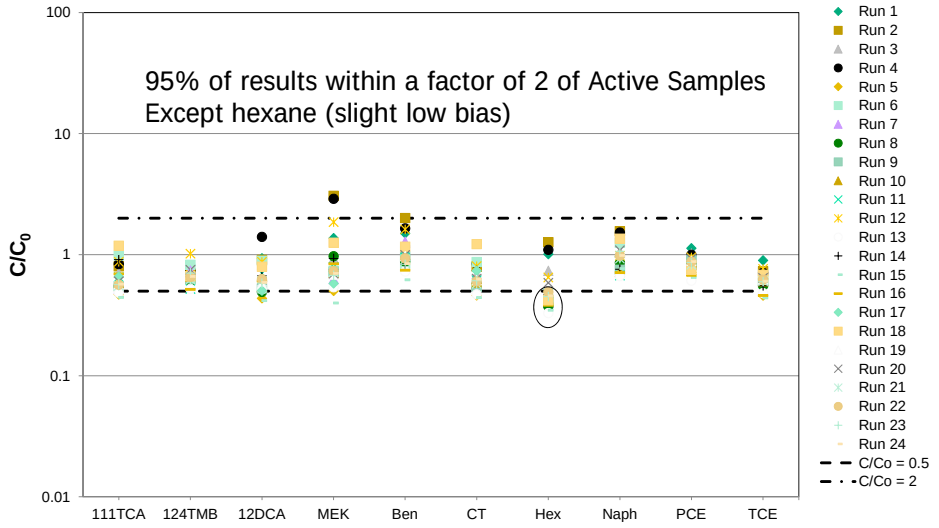
Fractional Factorial Testing

Run #	Approximate Concentration (ppbv)	Approximate Temperature (°C)	Face Velocity (m/s)	Duration (days)	Approximate Humidity (%R.H.)
1	100	17	0.41	1	90
2	1	17	0.014	1	90
3	100	30	0.41	1	30
4	1	30	0.014	1	30
5	100	30	0.41	7	90
6	1	30	0.014	7	90
7	100	17	0.41	7	30
8	1	17	0.014	7	30
9	50	20	0.23	4	60
10	50	20	0.23	4	60
11	100	17	0.014	1	30
12	1	17	0.41	1	30
13	100	17	0.014	7	90
14	1	17	0.41	7	90
15	100	30	0.014	7	30
16	1	30	0.41	7	30
17	100	30	0.014	1	90
18	1	30	0.41	1	90

10

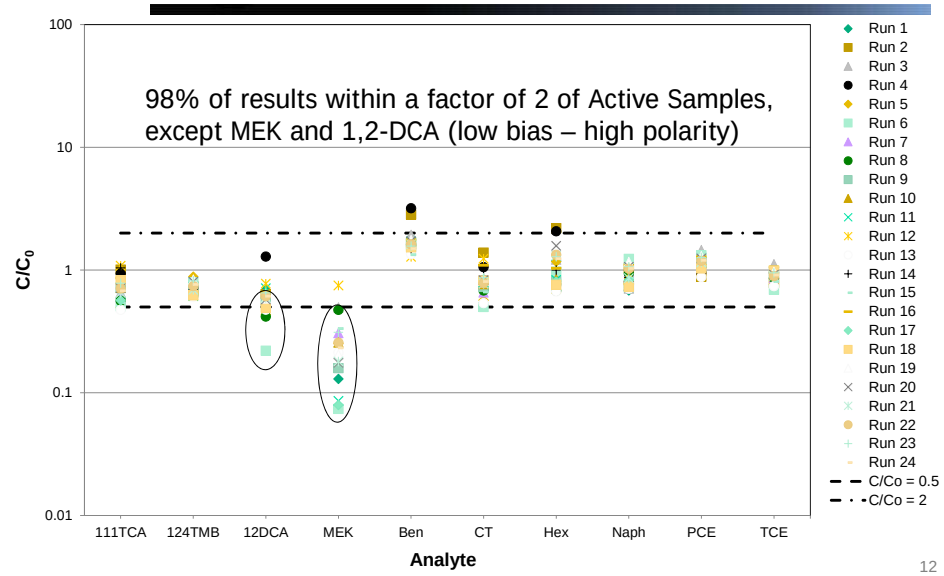
Geosyntec consultants

ATD Tenax TA



Geosyntec consultants

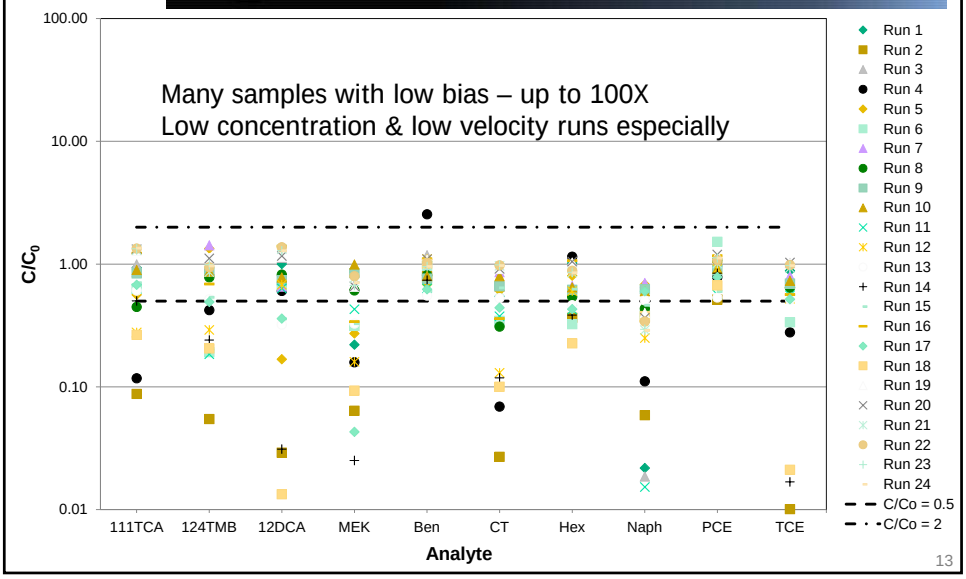
ATD Carbopack B



12

Geosyntec consultants

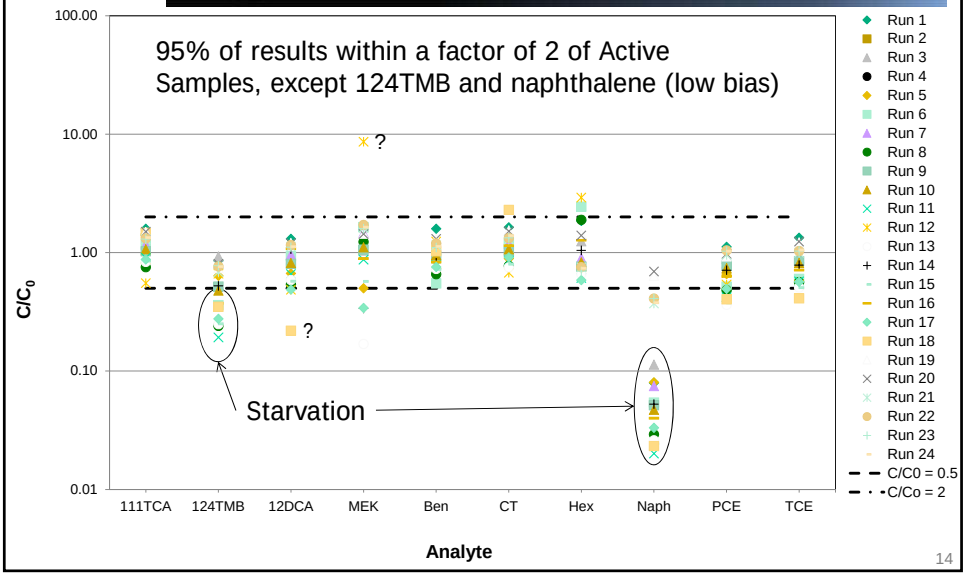
SKC Ultra



13

Geosyntec consultants

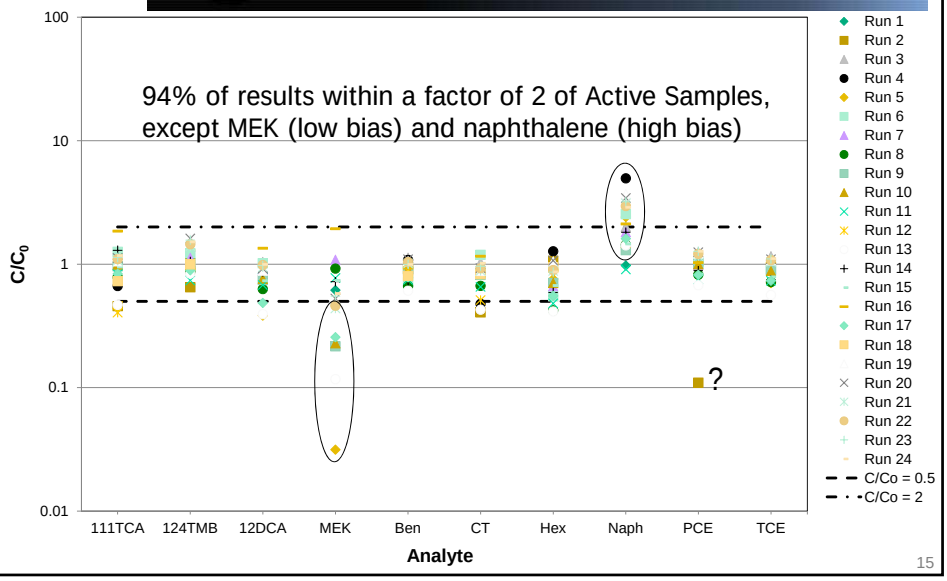
Waterloo Membrane Sampler



14

Geosyntec consultants

Radiello



15

Table 1: Statistical Significance of the Main Factors in the Fractional Factorial Experiments

Sampler Type	Analyte	Relative Humidity	Temperature	Face Velocity	Exposure Time	Concentration
ATD Carbopack	1,1,1-Trichloroethane	0.0778	0.0281	0.0106	0.0003	<.0001
ATD Carbopack	1,2,4-Trimethylbenzene	0.3181	0.0009	0.1245	0.5664	0.0011
ATD Carbopack	1,2-Dichloroethane	0.0012	0.6819	0.7406	<.0001	0.1371
ATD Carbopack	2-Butanone (MEK)	0.0693	0.4097	0.0603	0.7378	0.0119
ATD Carbopack	Hexane	0.7999	0.2913	0.4002	0.0272	0.1177
ATD Carbopack	Benzene	0.4718	0.2468	0.0547	0.0023	0.0331
ATD Carbopack	Carbon tetrachloride	0.0434	0.2975	0.3501	<.0001	<.0001
ATD Carbopack	Naphthalene	0.2629	0.6088	0.293	0.007	0.0778
ATD Carbopack	Trichloroethene	0.0113	0.2781	0.0002	<.0001	0.9484
ATD Carbopack	Tetrachloroethene	0.8513	0.004	0.0071	0.8484	0.0727
ATD Tenax	1,1,1-Trichloroethane	<.0001	0.2715	0.0021	<.0001	<.0001
ATD Tenax	1,2,4-Trimethylbenzene	0.9169	0.8868	0.0121	0.0296	0.2864
ATD Tenax	1,2-Dichloroethane	0.9154	0.8908	0.4733	<.0001	<.0001
ATD Tenax	2-Butanone (MEK)	0.7719	0.0799	0.1479	<.0001	<.0001
ATD Tenax	Hexane	0.6362	0.21	0.6114	<.0001	0.1148
ATD Tenax	Benzene	0.8106	0.0059	0.438	<.0001	0.0442
ATD Tenax	Carbon tetrachloride	<.0001	0.0229	0.0159	<.0001	<.0001
ATD Tenax	Naphthalene	0.311	0.2147	0.565	0.025	0.0347
ATD Tenax	Trichloroethene	0.5875	0.0002	0.0153	<.0001	0.475
ATD Tenax	Tetrachloroethene	0.3221	0.4522	0.11	<.0001	0.9827
RADIELLO	1,1,1-Trichloroethane	0.1005	0.0261	0.003	0.0899	0.0548
RADIELLO	1,2,4-Trimethylbenzene	0.6688	0.0007	<.0001	0.1133	0.0451
RADIELLO	1,2-Dichloroethane	0.0005	0.054	0.0002	0.0327	<.0001
RADIELLO	2-Butanone (MEK)	<.0001	0.5801	0.0003	0.0738	<.0001
RADIELLO	Hexane	0.1795	0.0066	0.0021	<.0001	0.0035
RADIELLO	Benzene	0.0047	0.0496	0.0012	<.0001	0.6113
RADIELLO	Carbon tetrachloride	0.4994	0.0143	0.0513	0.1724	0.9018
RADIELLO	Naphthalene	0.6635	0.0008	0.933	0.1183	0.0005
RADIELLO	Trichloroethene	0.001	0.0032	<.0001	0.0002	0.0169
RADIELLO	Tetrachloroethene	0.2158	0.0023	<.0001	0.3477	0.9109
SKC	1,1,1-Trichloroethane	0.0906	0.1691	0.0055	0.0096	0.0001
SKC	1,2,4-Trimethylbenzene	0.1362	0.3054	0.0012	0.0004	<.0001
SKC	1,2-Dichloroethane	<.0001	0.5187	0.1033	0.9879	0.6424
SKC	2-Butanone (MEK)	<.0001	0.2819	0.3914	0.0073	0.0028
SKC	Hexane	0.0006	0.0398	0.012	0.4921	0.1584
SKC	Benzene	0.0318	0.0551	0.9085	0.0218	0.0125
SKC	Carbon tetrachloride	0.0223	0.2682	0.032	<.0001	<.0001
SKC	Naphthalene	0.1182	0.1437	0.6579	<.0001	0.1122
SKC	Trichloroethene	<.0001	0.9977	0.0306	0.5618	<.0001
SKC	Tetrachloroethene	0.4868	0.0368	0.018	0.0097	0.1261
WMS	1,1,1-Trichloroethane	0.0224	0.9489	0.0042	0.6355	0.4719
WMS	1,2,4-Trimethylbenzene	0.7716	0.7992	<.0001	0.1467	0.0194
WMS	1,2-Dichloroethane	0.7347	0.1749	0.0054	0.0325	0.1887
WMS	2-Butanone (MEK)	0.5881	0.3369	0.14	0.0319	0.0027
WMS	Hexane	0.6198	0.4942	0.022	0.0003	0.0001
WMS	Benzene	0.5712	0.9017	0.0328	0.0012	0.0099
WMS	Carbon tetrachloride	0.0016	0.3838	0.0035	0.0766	0.0553
WMS	Naphthalene	0.9025	0.4298	<.0001	0.5432	0.006
WMS	Trichloroethene	0.6289	0.0325	0.0006	0.8376	0.0124
WMS	Tetrachloroethene	0.5923	0.1477	<.0001	0.9894	0.0074

red highlighted cells indicate statistical significance when alpha=0.05, therefore, p-value<0.05 = significant

ANOVA Analysis

Highlighted cells are statistically significant at the 5% level.

Need to think about whether “statistically significant” is also “practically significant”

95% within 2X is actually pretty good

If only we could predict the challenging compounds

16

Geosyntec consultants

Field Testing of Indoor Air

Navy San Diego, CA
Cherry Point, NC
CRREL, NH

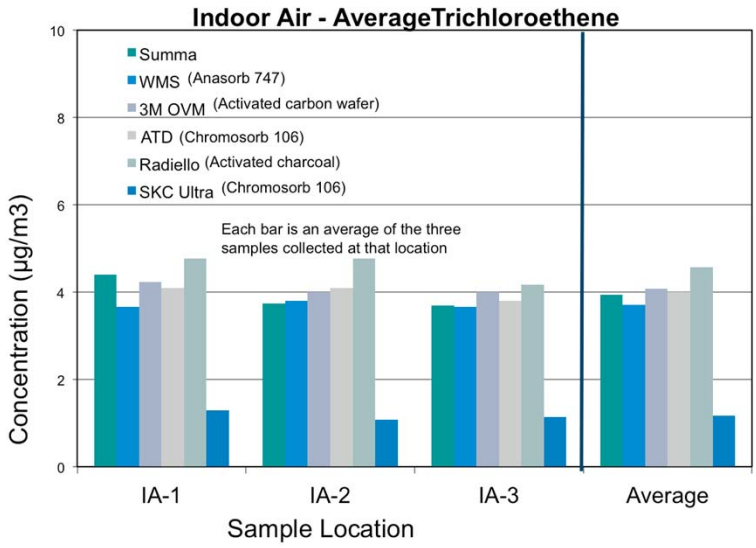
3 locations/site
5 passive samplers
Summa cans
Triplicates of each

Thanks to Ignacio Rivera of SPAWAR, Jason Williams of Cherry Point and Louise Parker of CRREL

17

Geosyntec consultants

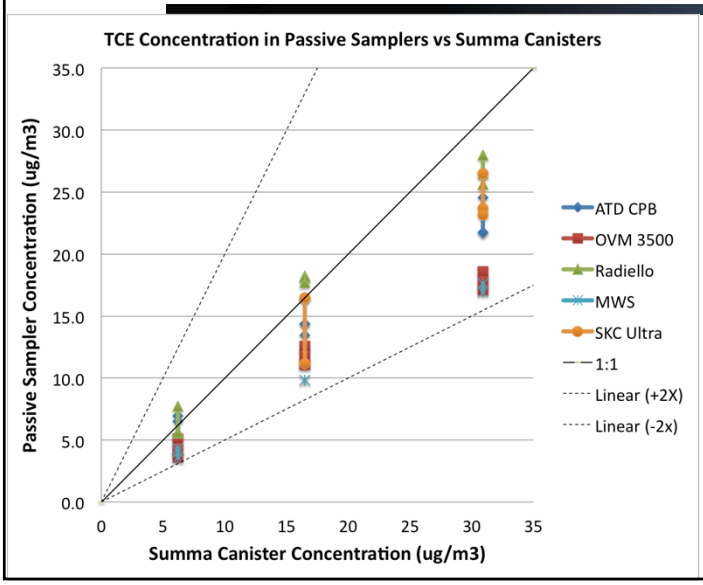
Indoor Air TCE at San Diego



18

Geosyntec consultants

Indoor Air at CRREL

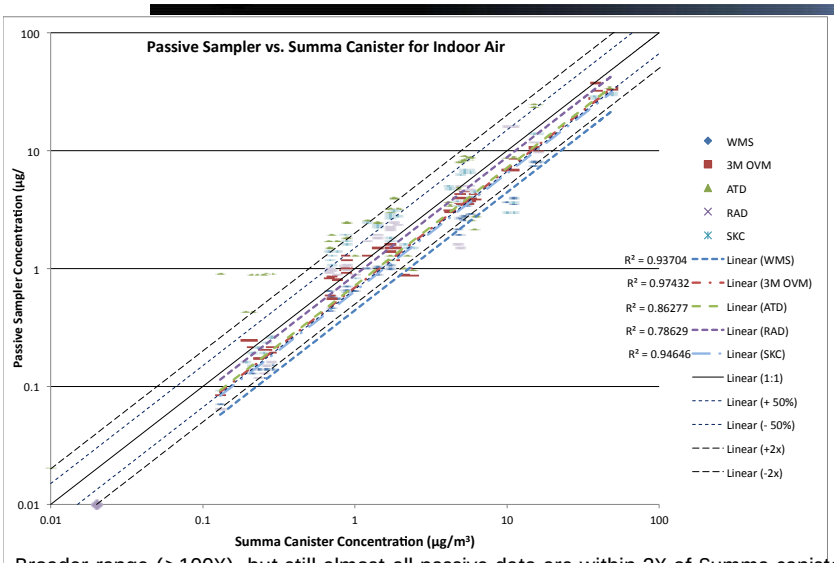


All passive sampler results were within 2X of Summa canister data for TCE

19

Geosyntec consultants

Indoor Air VOCs at Cherry Point



Broader range (>100X), but still almost all passive data are within 2X of Summa canisters

20

Geosyntec consultants

High Concentration Lab Tests

(To mimic soil gas conditions)

21

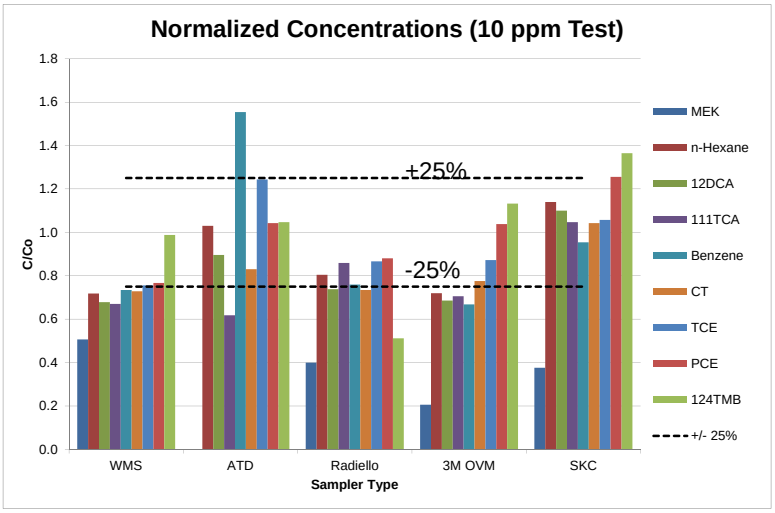
Geosyntec consultants

High Concentration Lab Tests

22

Geosyntec consultants

High Concentrations Test Results



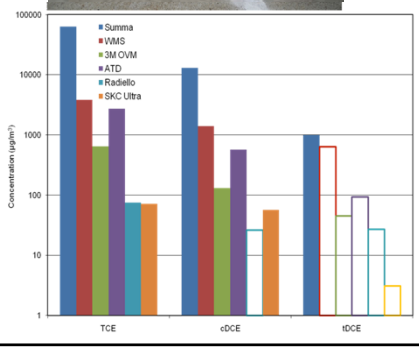
23

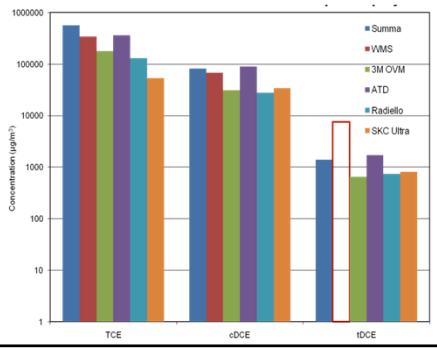
Geosyntec consultants

Sub-Slab – Navy San Diego

Sub-slab samples only
Fully-passive and with PID purging (flow-through)

Starvation proportional to uptake rate
Less starvation for semi-passive samples





24

Geosyntec consultants

Modified Uptake Rates

Lower uptake rate = less starvation

SKC Ultra II and 12-hole Cap

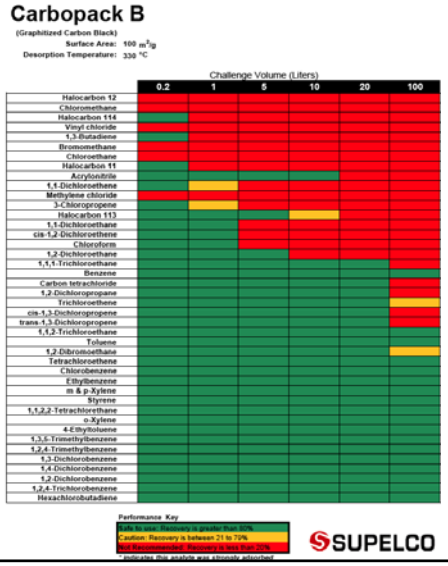
ATD Tube & Pinhole Cap

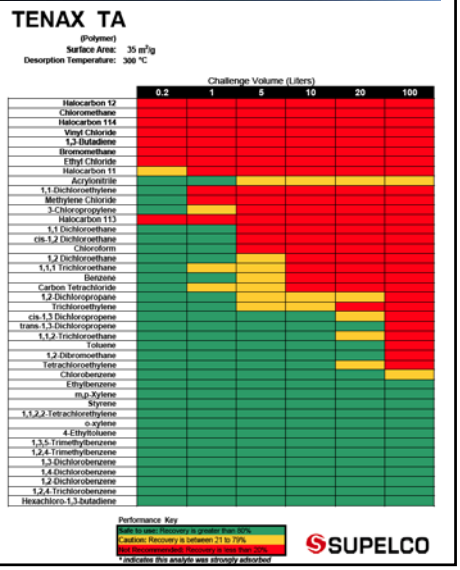
WMS and Low-Uptake WMS

25

Geosyntec consultants

Sorbent Selection





Geosyntec consultants

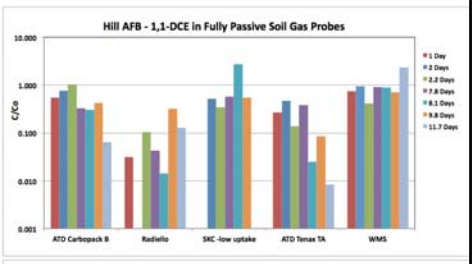
Soil Gas @ 12 ft – Hill AFB

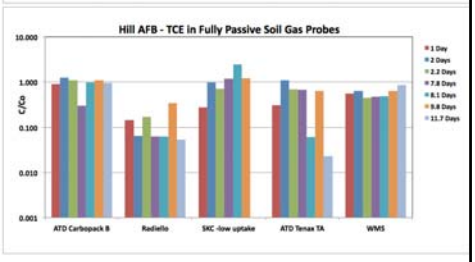
6 probes -12 ft deep

Latin Square Design

1 to 12 day exposures

C_o Measured using combination of Summa and Hapsite GC/MS

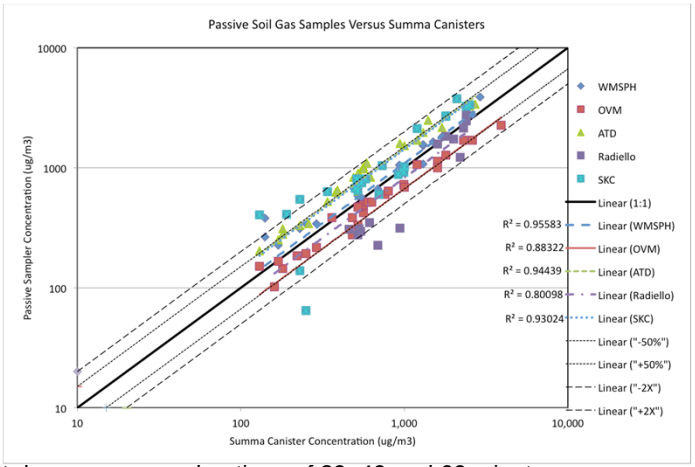




Negative bias for long duration with ATD-Tenax
Negative bias for high uptake rate (Radiello)
Otherwise, encouraging results for TCE and DCE

Geosyntec consultants

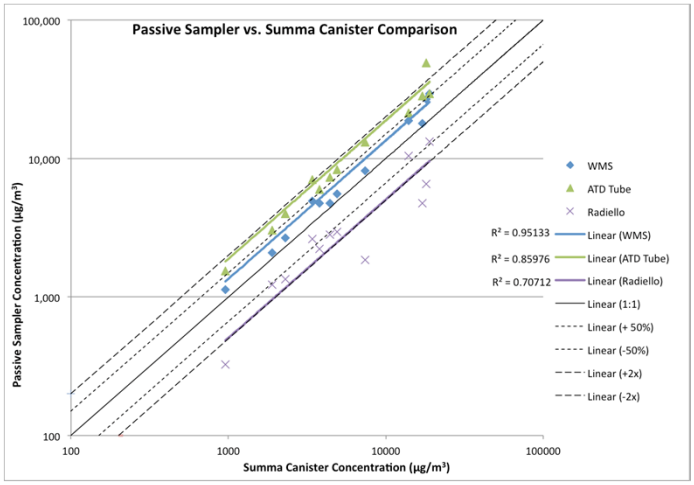
Soil Vapor Sampling – NAS JAX



Probes to 3-4 feet deep, exposure durations of 20, 40 and 60 minutes
Strong correlations, regression slopes all near 1.0

Geosyntec consultants

Passive Sub-Slab – NAS JAX

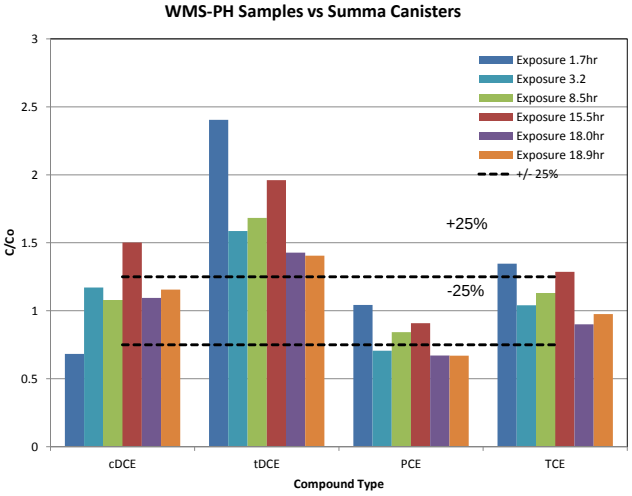


Limited to 1-inch diameter or less – Low-Uptake Rate Samplers

29

Geosyntec consultants

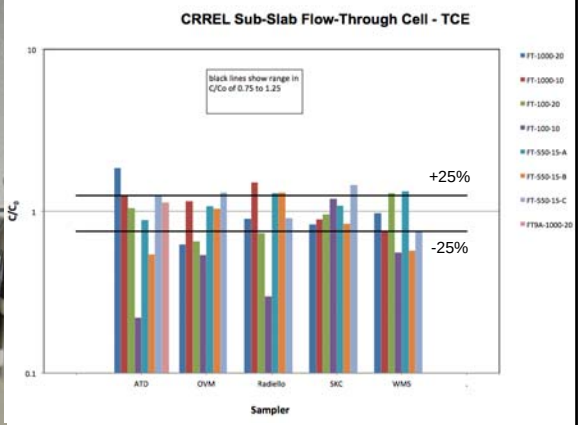
Temporary Passive - NAS JAX



30

Geosyntec consultants

Flow-Through Cell – CRREL

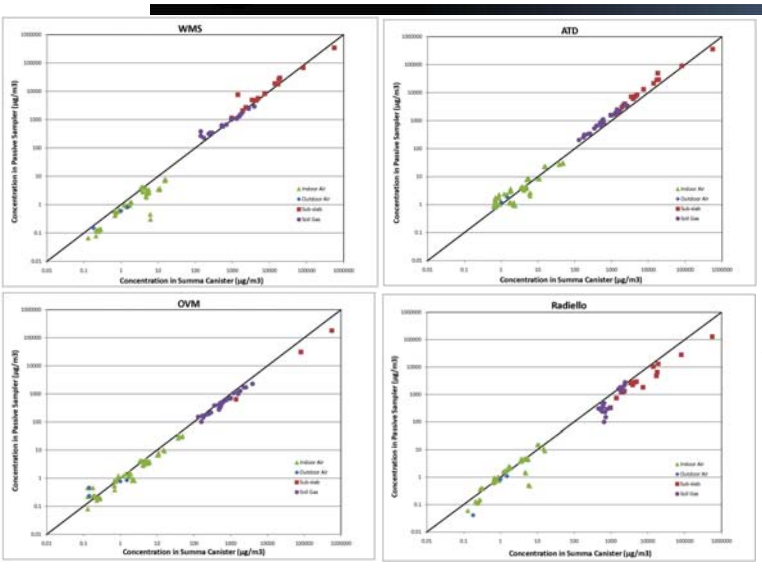


Flow-through cell to avoid starvation by design
No starvation for high-uptake rate samplers
Negative bias only for short duration/low-flow (insufficient purging)

31

Geosyntec consultants

Overall Correlation between Passive and Active Samplers



Strong correlation to conventional samples over 6+ orders of magnitude

Quantitative results for soil vapor (a breakthrough)

32

Geosyntec consultants

Cost Comparison

Simple comparison:

- 6 indoor samples
- 2 outdoor samples
- 6 sub-slab samples

Summa	WMS	Radiello	ATD	3M OVM	SKC
$6,810	$3,670	$3,590	$3,590	$3,610	$4,100

Ballpark 50% cost for passive samplers versus Summa cans

(even with some side-by-side Summa cans for benchmarking, you can still save a lot of money)

34

Geosyntec consultants

Take-Home Messages

- Passive Sampling is becoming a reality for VI assessment
  - Strong positive correlation with Summa cans
  - Generally good consistency, but sensitive to wind, rain, temp.
- Minimize variability:
  - Integrate over time to manage temporal variability for indoor air
  - Simpler protocols for soil gas sampling – less operator error
- Benchmarking is recommended in the near-term
  - 1 of 10 samples collected with a duplicate by Summa/TO-15
  - Accounts for site-specific conditions, challenging compounds
- Study design takes a little more thought
  - Different samplers have different pros and cons
  - Cost savings make it well worthwhile

35

Geosyntec consultants

Acknowledgments

- Funding gratefully acknowledged from:
  - ESTCP ER0830
  - U.S. Navy Environmental Sustainability Development to Integration (NESDI) Program
  - U.S. Army Corps of Engineers
  - Ontario Ministry of the Environment
  - Anadarko Petroleum Corporation
  - Geosyntec Consultants, Inc.

36

Geosyntec consultants

Questions/Comments?

tmcalary@geosyntec.com